BELLCOMM, INC.

SUBJECT: The Contribution of the Q-Ball to the Emergency Detection System - Case 120

DATE: November 2, 1964

FROM: P. R. Knaff
M. M. Purdy

## SUMMARY

This memorandum presents a summary evaluation of the contribution of the q-ball to the Emergency Detection System (EDS). In the context of EDS requirements, the q-ball provides the crew with information needed to warn of vehicle breakup. Of potential sensors, the q-ball offers the best combination of parameter relevance, reliability, and availability. Its use in the EDS is warranted at this time.

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MEMORANDUM FOR FILE

The function of the Apollo-Saturn Emergency Detection System (EDS) is to give advance warning of conditions which pose an immediate threat to the flight crew. The purpose of this memorandum is to summarize the contribution of the q-ball to EDS.

Physically located at the extreme top of the launch escape tower, the q-ball has a spherical front surface on which four ports are located. These ports, two of which lie in the pitch plane and two of which lie in the yaw plane, lead to pressure transducers. Differences in pressure ($\Delta p$) between ports will be some function of angle of attack, dynamic pressure, and a corrective term dependent on mach number.

The use of the q-ball for the EDS was an outgrowth of a launch vehicle failure effects analysis which led to a flight mechanics study of the consequences of Guidance and Control System (G&C) malfunctions. Among the G&C failure modes of major concern were those causing slow divergence from nominal vehicle attitudes which ultimately resulted in vehicle breakup. One goal of the EDS is to predict vehicle breakup reliably and with as much warning time as possible. It is necessary, however, to achieve this goal without excessively compromising the probability of mission success, as would occur with an inadvertent abort. Increased precision in predicting vehicle breakup appears to be the best approach to satisfy both criteria.

Vehicle breakup can be predicted as a function of three primary variables for the failure modes cited above:

$\alpha$ (Angle of attack)

q (Dynamic pressure) = f(t) (flight time)

$\beta$ (Thrust vector angle)

The relationship between these variables, presented in Figure 1, shows that structural limits of the vehicle can

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be expressed in terms of $\alpha$, $\beta$, and t, for a nominal boost trajectory [since $q = f(t)$]. Figure 1 also shows expected maximum values of $\alpha$; and that the differences between the expected and the limit values of $\alpha$ are smallest at about 63 seconds after lift-off, near the region of $q_{max}$. Only three current spacecraft displays lend themselves to the prediction of vehicle breakup when caused by slow divergence failures. They are the display of the q-ball output, the Flight Director Attitude Indicator (FDAI), and the event timer. Attitude error is displayed by the FDAI, and this parameter can be used to infer $\alpha$*. This inference about $\alpha$, in combination with an estimate of q (via the event timer), can lead only to a gross estimate of whether the vehicle is in danger of breaking up. The output of the q-ball will be a function of $\Delta p$, where $\Delta p = k\alpha q$, and k is a function of mach number. Thus, of all the CM displays, the q-ball output will provide the information which most accurately shows vehicle status with respect to operational limits.

On the other hand, it may be observed that $\beta$ is not currently displayed in the CM. Yet Figure 1 shows that the operational limits of the launch vehicle are affected by $\beta$. The foregoing discussion, therefore, is not intended to imply complete satisfaction with the q-ball output; but, only that it currently provides the best integrated information to the crew regarding the breakup limits.

Essentially the same conclusion was reached by a working group set up by the Joint Crew Safety Panel and charged with recommending the most appropriate parameter to be sensed to satisfy crew safety requirements. The results of this study, as reported to the Ninth Joint Crew Safety Panel Meeting, contained the following supporting arguments:

1. The limiting conditions are determined by the launch vehicle, not the launch escape vehicle (LEV). [Had the LEV limits been determining, it might have been more appropriate to sense $\alpha$ alone.]

2. Launch vehicle limiting conditions are structural limits and are a function of $\alpha q$ or $k\alpha q$ ($= \Delta p$).

3. Selection of the $\Delta p$ parameter has the virtue of design simplicity, since the $\Delta p$ signal is directly available from the q-ball. [An $\alpha q$ (or an $\alpha$ only) display signal from the $\Delta p$ output of the q-ball would require removal of the influence of mach (or both mach and q). Removal of mach and q influences would require prediction and preprogramming of these parameters.]

*It should be noted that the correlation between attitude error and $\alpha$ is not always high.

In terms of its impact on Apollo Program costs and schedules, the choice of the q-ball also appears to be justified. A q-ball has been flown on the early S-I flights as a backup control sensor. An instrumentation version will be flown on flights SA-9, SA-8, and SA-10. The EDS q-ball is presently in the last stages of development and will be flown first on flight SA-201. With this background, no schedule slippages or unanticipated development costs are expected with its use in the S-1B flight series.

In conclusion, warning of vehicle break-up is an EDS requirement. For "slow divergence" failure modes leading to vehicle break-up, the q-ball currently offers the best combination of parameter relevance, reliability, and availability. Its use in the EDS is warranted at this time.

P. R. Knaff

M. M. Purdy

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Attached:
Figure 1

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MSFC, to the Ninth Apollo-Saturn
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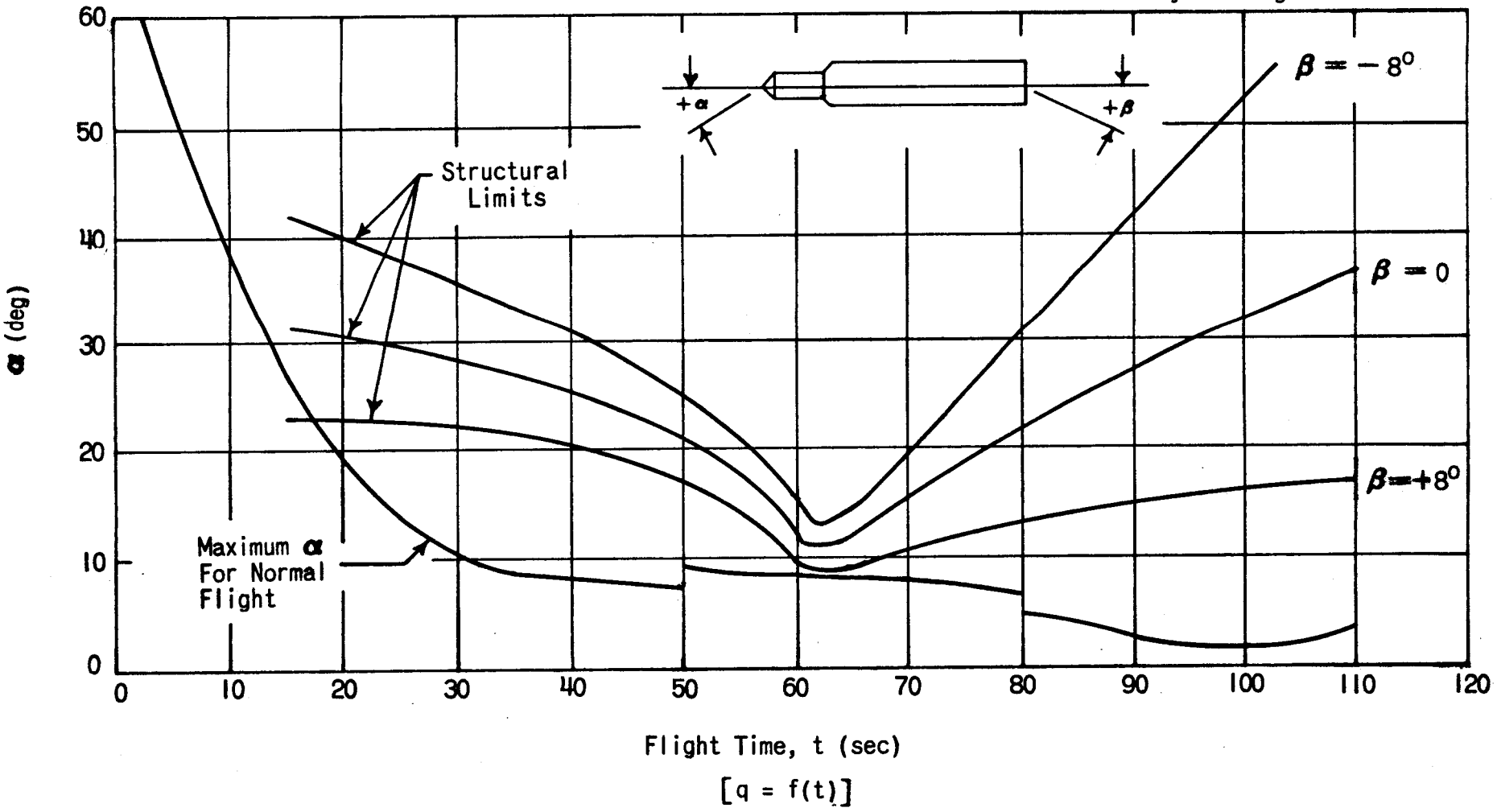


FIGURE 1 THE RELATIONSHIP BETWEEN LAUNCH VEHICLE STRUCTURAL LIMITS AND $\alpha$, $\beta$, AND t, WHERE q = f(t).